BEES for ANTS

Biologically Inspired Engineering for Exploration Systems Concepts as applied to Autonomous NanoTechnology Swarm Architecture

P.E. Clark and M.L. Rilee
L3 Communications, GSI

S.A. Curtis, W. Truszkowski, C.Y. Cheung, G. Marr
NASA/GSFC

M. Rudisill
NASA/LARC

ANTS as Biologically Inspired Engineering for Exploration Systems

Mission architecture for functions and activities inspired by ant colony analogue.

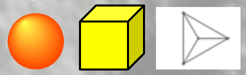
Based on Hierarchical Hive (multilevel, dense heterarchy) analogue organization.

> Based on Addressable, Reconfigurable Technology (ART): addressable, self-configuring network of nodes (synthetic nervous system) reversibly deploy struts and shells (synthetic skeletal muscular framework and skin), allowing transformation in form and thus function.

Undifferentiated components designed for shape shifting to achieve optimal mobility in environments ranging from space to rugged surfaces, and for effective gathering and management of energy and information resources in those environments.

The Tetrahedral Structure: Properties and Natural Analogues

Minimal structure (fewest edges and least volume per surface area) compared to other polyhedra.



Triangulated structure gives great mechanical stability.

Irregular Tetrahedra most effectively fill volume as triangular facets fill surface area.

Tetrahedron properties make it ubiquitous as a stable form in nature: as organic (C tetrahedral coordination) and non-organic solid (silicate) systems.

Silicate Tetrahedra (Si:O) arrangements:

nesosilicate

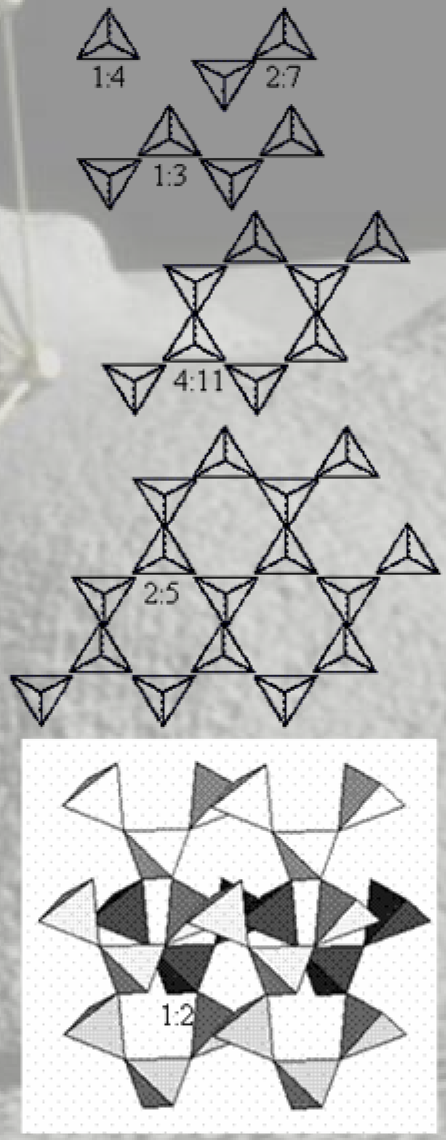
sorosilicates

chain silicates

cyclosilicates

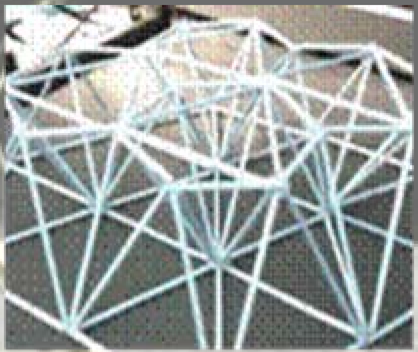
sheet silicates

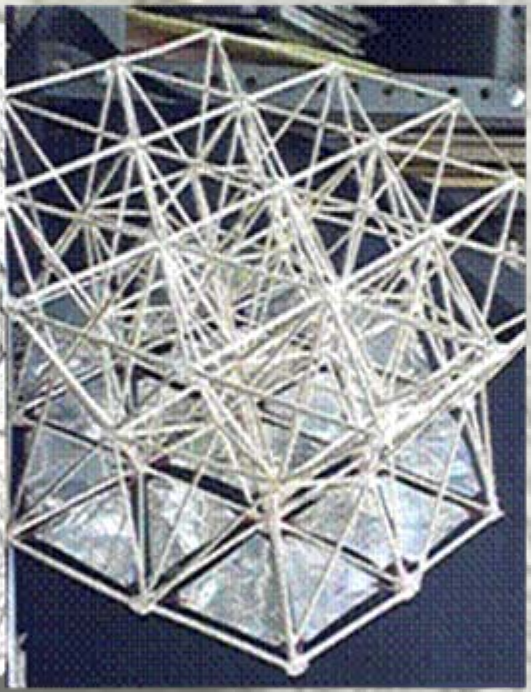
tektosilicates



ANTS Tetrahedral Structure

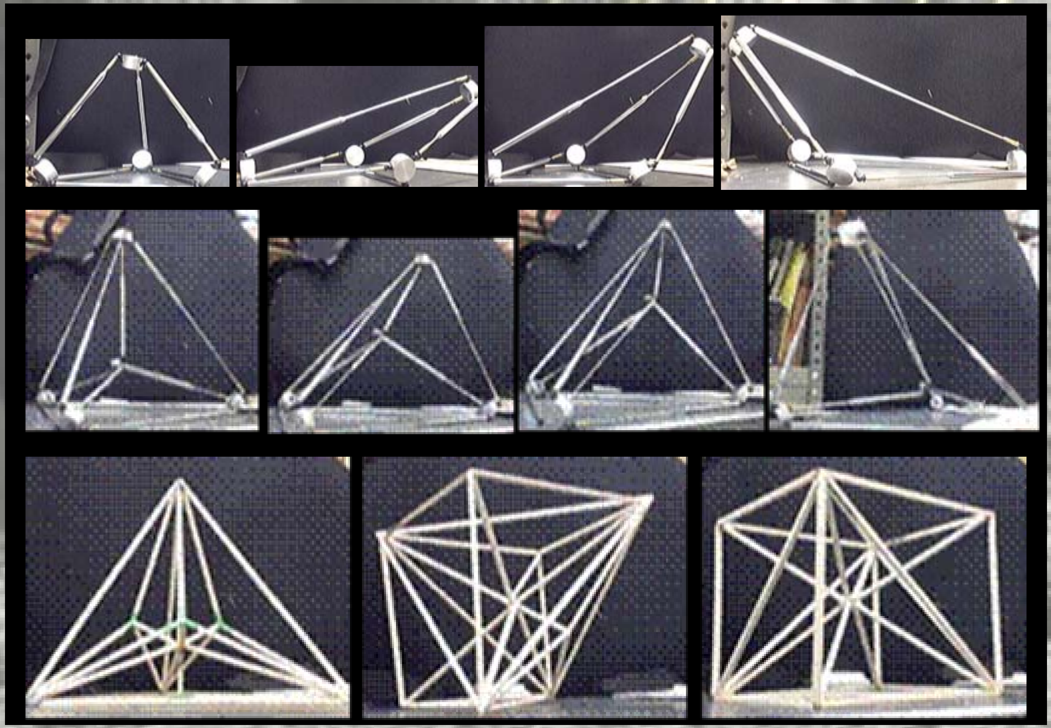
The continuous tetrahedral structure consists of layers of nodes with alternating patterns (top left), interconnected by struts (top right). Tetrahedra become irregular in shape, conforming to required shape to fill space, to make continuous structures (bottom right), instead of remaining regular and requiring insertions of other polyhedra to fill space.





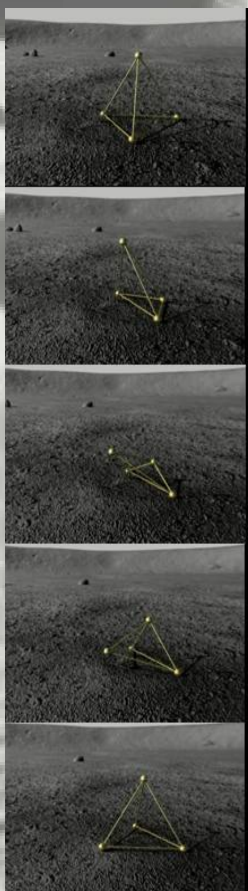
ANTS Walkers: Simple Tetrahedral Structures

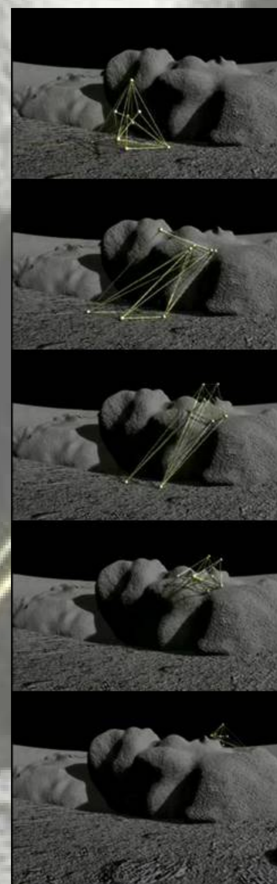
Three tetrahedral walkers illustrate the nodes and strut architecture, and motion. A single walking tetrahedron, and tetrahedron with a central node to form a 4Tetrahedral Walker, tip over as struts are lengthened to shift the center of mass in the direction of motion. The addition of the central node allows more rapid shift in center of mass. In the 12Tet model note complete transformation from the highly angular tetrahedral shape for tipping to nearly spherical shape for movement to cubic shape for stable standing.

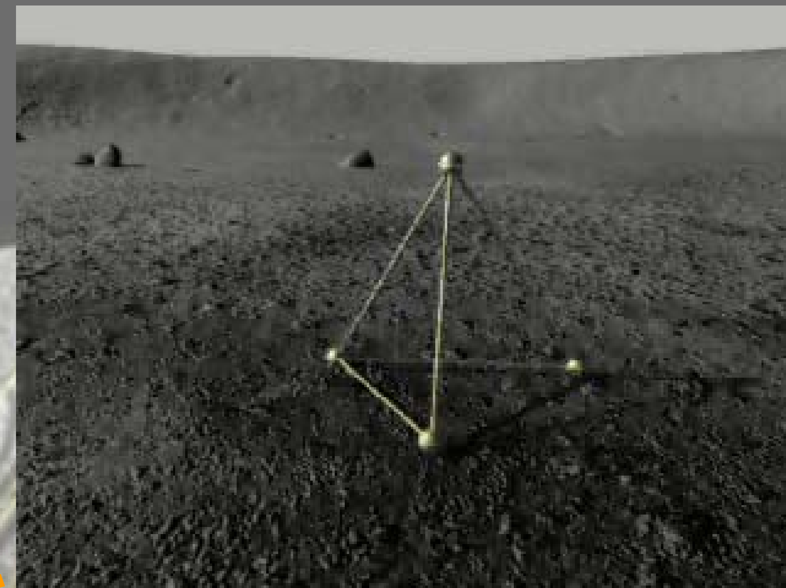


Tetrahedral Walkers: Locomotion

ANTS walkers illustrate the nature of tetrahedral locomotion. Simple tetrahedron walkers exhibit punctuated flip flops, but with the 12Tetwalker, more complex, continuous motion emerges.



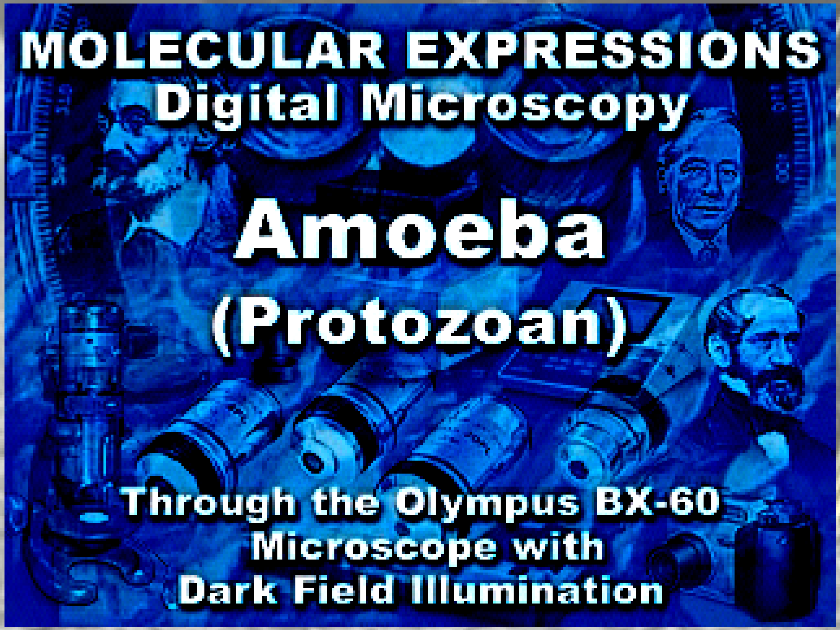




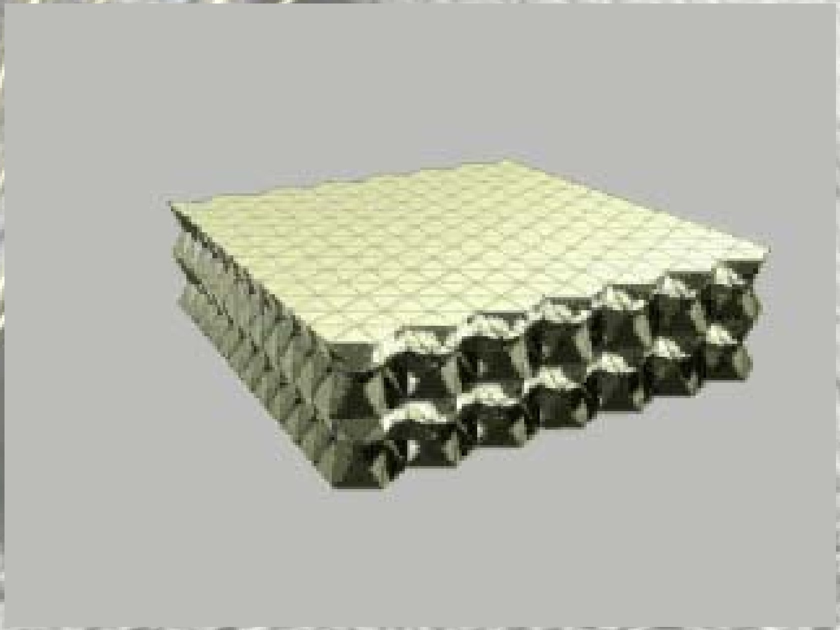
Biological Analogues for Locomotion: Amoeboid Movement and Shape Shifting

Biological Mechanism: Amoeboid movement with many degrees of freedom resulting from flow at cell surface through rolling conveyer belt movement.

ANTS Continuous tetrahedral locomotion. Complex transformations with many degrees of freedom for Lander Amorphous Rover Antenna (LARA) vehicle from flattened for stable landing to flow through rolling or slithering (elongated in direction of slope) for surface mobility regardless of terrain, to hemispheric for communication or shelter.



* *



Biological Analogues for Strut Deployment: Telescoping

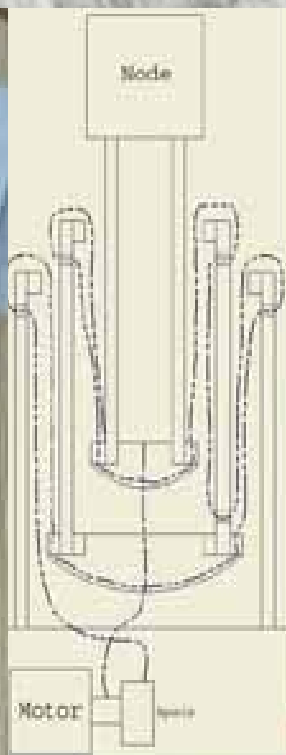
Biological Mechanisms From left to right movement of gills of aquatic insect, and gaster of ant, both involving respiration, ovipositor of dragon fly, and vertebrate striated muscle, from respective websites below.

ANTS Current Strut Model On left is thin wall brass telescoping strut. On right is PVC pipe telescoping strut with spring on cable mechanism.

http://trog.cs.umb.edu/streams/streamsKey/thm/Taenioptteryx_02_thm.jpg
http://www.agr.state.ga.us/assets/images/Fire_ant.png for fireant
http://rbcm1.rbcm.gov.bc.ca/nh_papers/img_nhpapers/dfly019s.jpg
http://www.udel.edu/Biology/Wags/histopage/empage/em/em.htm

Biological Analogues for Strut Deployment: Angling/Pulley Mechanism

Biological Mechanisms: Jelly fish, box jelly from warm, surface waters of tropics on right, and unknown jelly from deep ocean on left, both using hook and pull mechanism to move prey to central feeding tube. Websites given below.



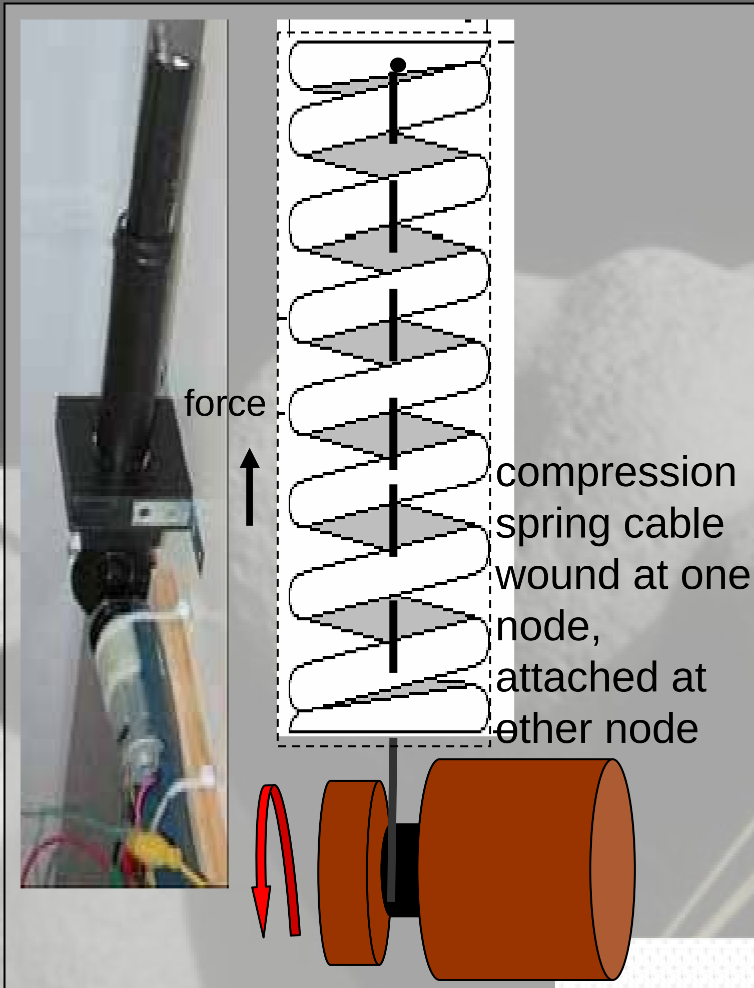
ANTS Power Driven String and Pulley Strut Deployment. Diagram shows string path in brass telescoping strut.

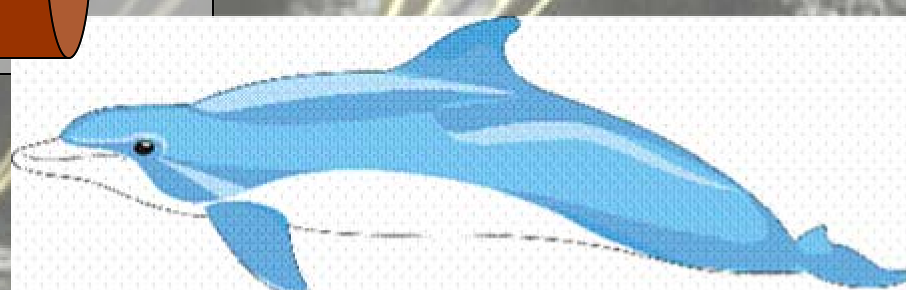
http://oceanexplorer.noaa.gov/explorations/02sab/logs/aug19/media/jelly_600.jpg
http://www.ucmp.berkeley.edu/cnidaria/C_sivickisi.html

Biological Analogues for Strut Deployment: Compressional Springs

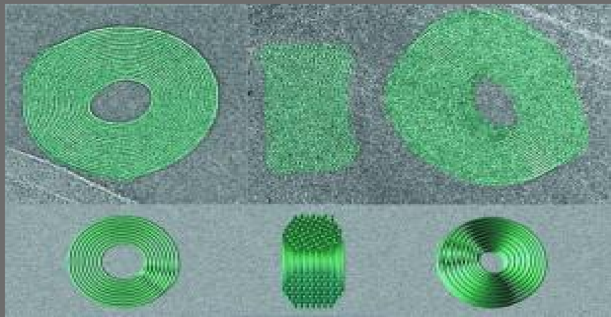
Biological Mechanism Two regions in tail acting as opposing pair of compression springs to create pogostick like motion for swimming with little energy expenditure in dolphin.

ANTS Power Driven Compression Spring Strut Deployment shown in picture and diagram of mechanism.





Dolphin http://biology.usgs.gov/features/kidscorner/games/ocnscramb_ans.html
Mechanism http://biomechanics.bio.uci.edu/_html/nh_biomech/dolphin_spring/dolphin.htm



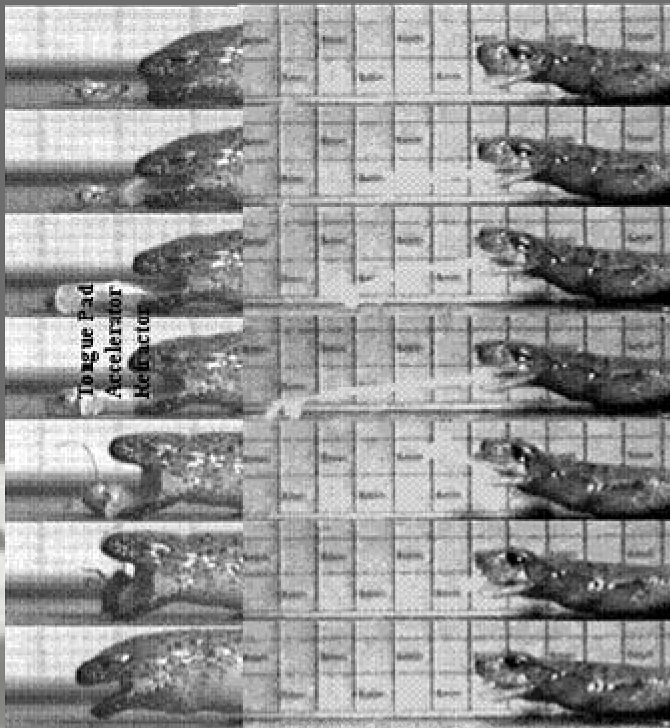
Biological Analogues for Strut Deployment: Constant Force Spring Mechanisms

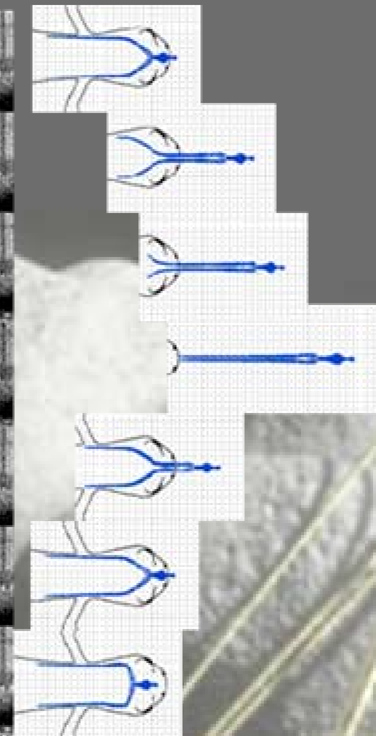
Biological Coiling Mechanisms include the recently discovered coiling of DNA to minimize surface area and potential damage during ‘storage’, the toroidal coiling of paleogastropod shell to larger volume protected interior for vital organs, and defensive coiling of millipede. Websites given below.

ANTS Power driven constant force tape device, with pairs of oppositely wound tapes joined for opposing force strength. Proposed for future MEMS nodes.

http://www.museum.vic.gov.au/collections/sciences/natfoss.asp
http://www-vis.lbl.gov/Vignettes/KDowning-DNA/
http://www.sardi.sa.gov.au/pages/entomolo/pdf/milliped_bailey.pdf

Biological Analogues: Opposing Force Mechanism

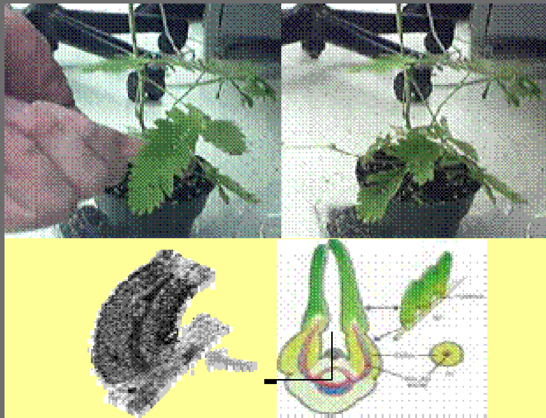




Biological Opposing Springs of Amphibian Tongue. Inner interleaved muscle acts as compressional spring connected to bone (accelerator). When reaches full extension, spirallay wrapped muscle acts as extensional spring and pulls back (rectractor), creating suction to hold prey at end of tongue (pad). (http://autodex.net)

*

*



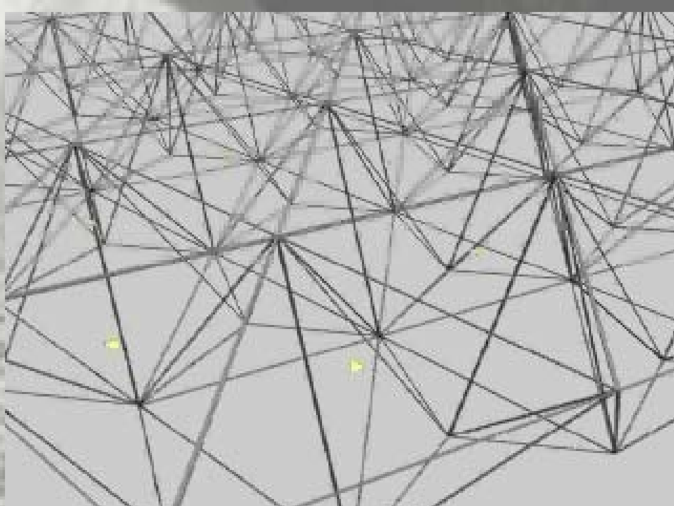
Biological Analogues for Surface Deployment: Plant Mechanisms

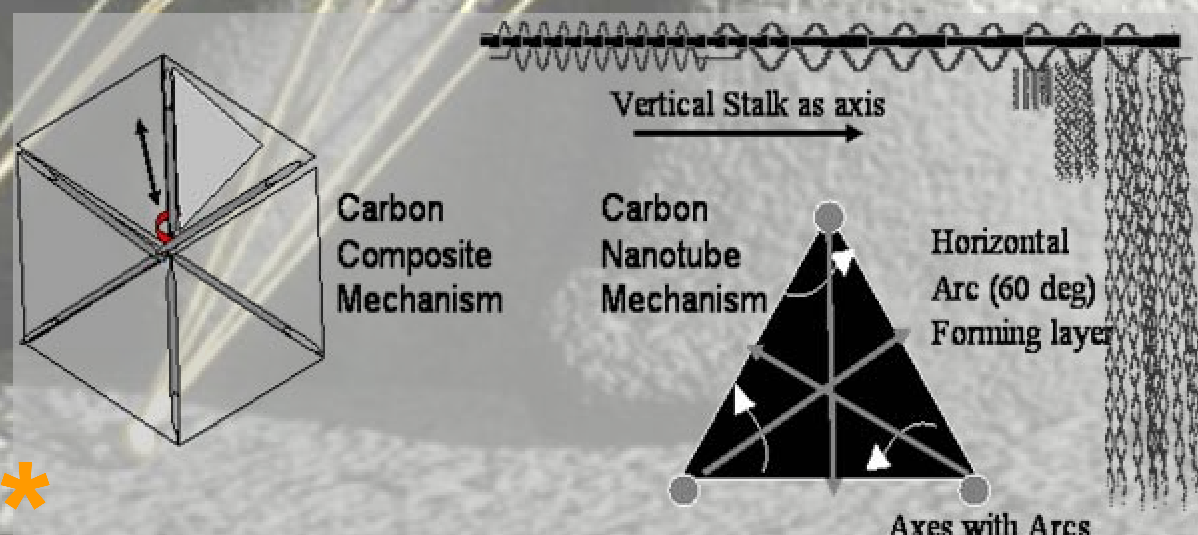
Biological Mechanism in Sensitive Plant. Leaf closure is a normal response to protect foliage, resulting from reduction in cell turgor, or osmotic water pressure, a kind of plant hydraulic response. Sensitive plant shows a particularly rapid response to touch (thigmonastic) and movement (seismonastic). Attached to the fronds are highly permeable motor organs, the pulvini, which contract due to outflow of water triggered by rise in sucrose on the side where the plant has been touched, and vice versa. Thus the mechanism is truly electrochemical. Carbon nanotubes exhibit structural changes in response to movement of electrons or protons (hydrogen bonding).

http://scidiv.bcc.ctc.edu/rkr/Biology203/lectures/EnvControl/EnvReg.html

Biological Analogues for Surface Deployment

ANTS Shell/Sheet/Sail Deployment Mechanism. As in plants, frequent deployment/stowing of surfaces will require efficient mechanisms. Models for two mechanisms described here use opposing force mechanisms. Sheets deploy as triangular sides of tetrahedra. In the MEMS level design, carbon fiber composite memory fabric is wrapped shade-like under compression on a roll which is attached to spring applying force in opposite direction. The NEMS level design uses Carbon Nanotubules directly. Vertical dendritic CNT stalks under compression are wrapped with tensional coils. When released, dendrites deploy in 60 degree arcs toward opposite side. The dendritic density and order determines reflectivity and strength. Such changes might be induced in CNTs through the flow of positive or negative charges.





*

Conclusion: Comparison of Biological and ANTS ART Mechanisms

Tetrahedral structures provide optimal stability and flexibility for both.

Due to its simplicity, telescoping is used extensively in more primitive organisms and in the prototype Tet Walker Node and Strut mechanisms.

The Angler/Pulley mechanism is efficient but suitable for applications with minimal torque requirement.

Biological spring mechanisms are used extensively, as opposing force mechanisms, providing power and efficiency. Single spring mechanisms in the early Tet Walker are powerful in principle but with large power requirement. Future designs should consider opposing mechanisms to minimize power requirement.

Biological constant force springs are typically used as efficient protection mechanisms, and could be efficient mechanisms for MEMS or NEMS level ANTS systems when used as opposite pair/opposing force mechanism.

As plants use powerful hydraulic mechanisms to reversibly deploy foliage, such mechanisms should be considered for the early ANTS surface deployment mechanisms, and potentially for early powerful strut deployment mechanisms.